NASA CR 185686 1 of 1

UNITED TECHNOLOGIES
HAMILTON STANDARD

SVHSER 10629

SPACE AND SEA SYSTEMS DEPARTMENT

FINAL REPORT

CONTRACT NAS9-17040

DEVELOPMENT OF A PRE-PROTOTYPE GENERIC WORK STATION/RESTRAINT SYSTEM FOR EXTRAVEHICULAR ACTIVITY

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

(NASA-CR-185686) DEVELOPMENT OF A PRE-PROTOTYPE GENERIC WORK STATION/RESTRAINT SYSTEM FOR EXTRAVEHICULAR ACTIVITY Final Report (Hamilton Standard) 42 p

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LYNDON B. JOHNSON SPACE CENTER

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I. INTRODUCTION

Present generation work restraints are limiting, either requiring excessive set-up time or dedication of the Remote Manipulator System (RMS) and operator. With the increase of planned Extravehicular Activity (EVA) for Space Station and Satellite servicing, a definite need exists for a portable work restraint that is easily set up and can be operated by one EVA crewman.

The purpose of the Generic Work Station/Restraint System (GWS) program was to design, fabricate, test, and deliver a Feasibility Test Unit for NASA's evaluation. Neutral buoyancy testing was used as part of an iterative design process which allowed for changes based on test performance.

A flight version of the GWS would make EVA work easier by reducing set-up time, eliminating the need for the RMS and operator, and allowing crewmen to position themselves in place.

II. DESIGN REQUIREMENTS AND GUIDELINES

The following is a list of the design requirements of the feasibility test unit delivered to NASA/JSC.

The GWS must:

a. Accommodate the male and female EVA astronaut population
b. Support EMU/MMU operations
c. React forces of 100 pounds in any direction
d. Be designed for one man operation
e. Function at -200°F to +250°F (flight hardware requirement)
f. Interface with predesignated work areas
g. Be integratable with undesignated work sites during unplanned EVA's
h. Total mass of system must not exceed 20 pounds
i. Not interfere with MMU operations
j. Operate in KC-135 zero-g flight as well as in a neutral buoyancy tank

Discussion:

The following is a discussion of how each of the design requirements was met or how they could be met.

a. The crewman interface is a standard step-in foot restraint on an adjustable down-tube. This allows for optional positioning of the control box with respect to crewman reach.

b. The GWS can be used with the MMU. The GWS is centered in front of the crewman and does not interfere with the present MMU. Folding handles would provide greater clearances to MMU control arms.

c. With NASA technical monitor's concurrence, the delivered GWS hardware was not built to withstand 100 pounds but rather a 60 pound limit to yield was used. This design can easily be upgraded to meet the 100 pound requirement by replacing "off the shelf" components with higher strength materials.

d. The GWS is designed for a one-man operation. In addition, only one hand is required to adjust position.

e. The thermal requirement of -200°F to +250°F was considered primarily as a flight hardware concern but this temperature range was taken into consideration during the concept selection phase of the program. The telescopic boom concept was eliminated due to the tolerance concerns which were amplified by the wide temperature range.

f & g. The present GWS configuration uses a handrail clamp designed by ILC/CLC for WETF testing. Concepts for various means of attachment to undesignated work sites are discussed later.

II. DESIGN REQUIREMENTS AND GUIDELINES (continued)

h. The total mass of the system exceeds the 20 pound requirement. Although the present design could see significant weight reductions, the associated increase in machining costs was not justified. The system weight is 79 pounds with 13.5 pounds comprising the foot platform alone. Most of the weight reduction could come from resizing of gears by using high strength materials rather than "off the shelf" parts. Reduction of gear sizes would allow for smaller housings at the control box, elbow, and wrist joints.

i. See b) above.

j. Although the GWS could be evaluated in a KC-135 flight, it is not designed to withstand the +3g acceleration with a test subject attached. With a minimum of 10 seconds ingress and 10 seconds egress, this would allow only 10 seconds of evaluation of the hardware for each zero-g profile. The neutral buoyancy tank is a better way to test and evaluate the GWS.

III. EVOLUTION OF DESIGN - A REVIEW OF CONCEPTS

The Generic Work Station was divided into three areas of study. (1) Crewman interfaces, (2) Structure interface and (3) Adjustment techniques.

Crewman Interfaces

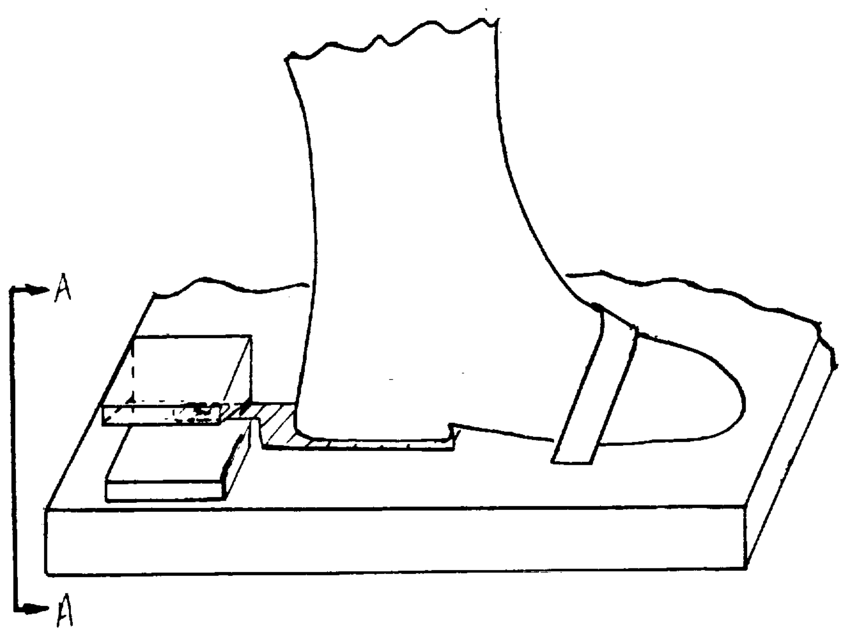
Several areas of attachment to the suited EVA crewman were investigated. The restraints can be broken down into three categories. The following figures show some of the concepts investigated and a brief discussion of advantages and limitations of each:

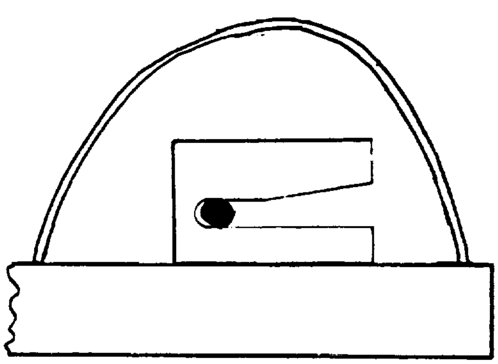
1. Foot Restraints:
   - o Toe hoop/heel spur (Figure 3-1)
   - o Inflatable bladder (Figure 3-2)
   - o Keyhole (Figure 3-3)
2. Waist/mid-body restraints
   - o MWS attachment (2 pt) (Figure 3-4)
   - o Integral HUT waist ring (Figure 3-5)
3. Other
   - o Toe/leg (Figure 3-6)
   - o Knee brace (Figure 3-7)

Structure Interface

The attachment of the work station to the work site can be accomplished most easily if a known standard interface exists. Those structures still in the design phase and all future ones can be designed with a common attachment for work restraints. Vehicles already in orbit would require different tools depending on the particular area which would require restraint attachment. The approach then, is to:

1. Develop several concepts for a standard attachment to be incorporated into all future structures in designated work sites and maintenance areas.
2. Design a tool or set of tools which will allow attachment to a variety of structures for undesignated work sites on a case by case basis.





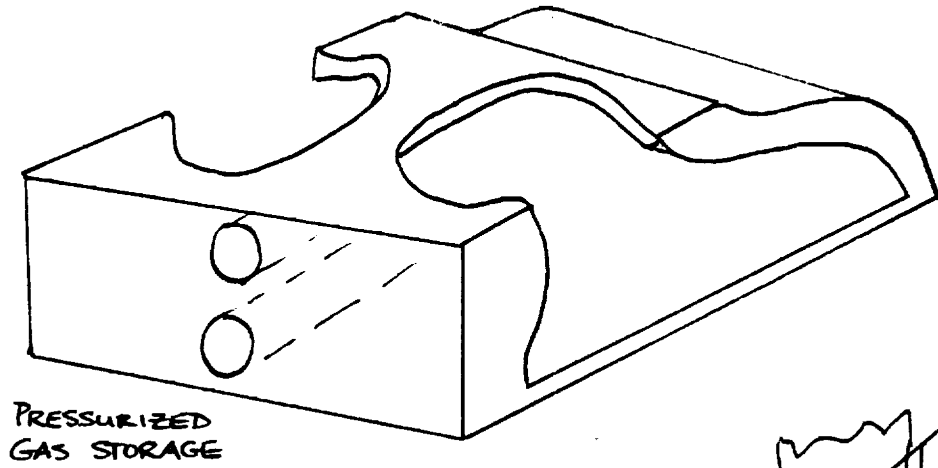
Advantages: - More tolerance at heel entry

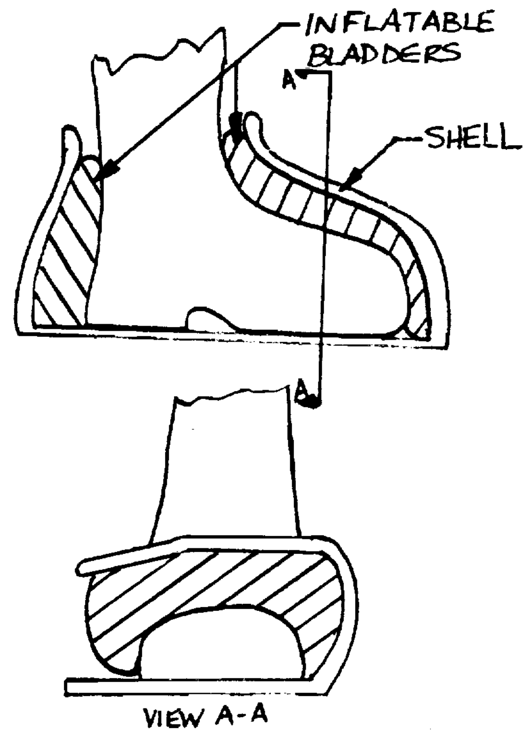
Limitations: - Heel spur projection may cause damage to another crew-man's suit or structure

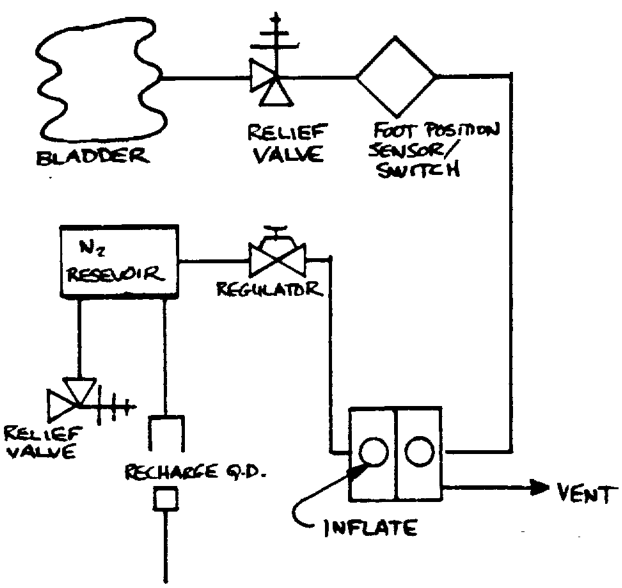
- Still a blind entry

FIGURE 3-1

TOE HOOP/HEEL SPUR FOOT RESTRAINT







Advantages: - Ease of ingress/ egress

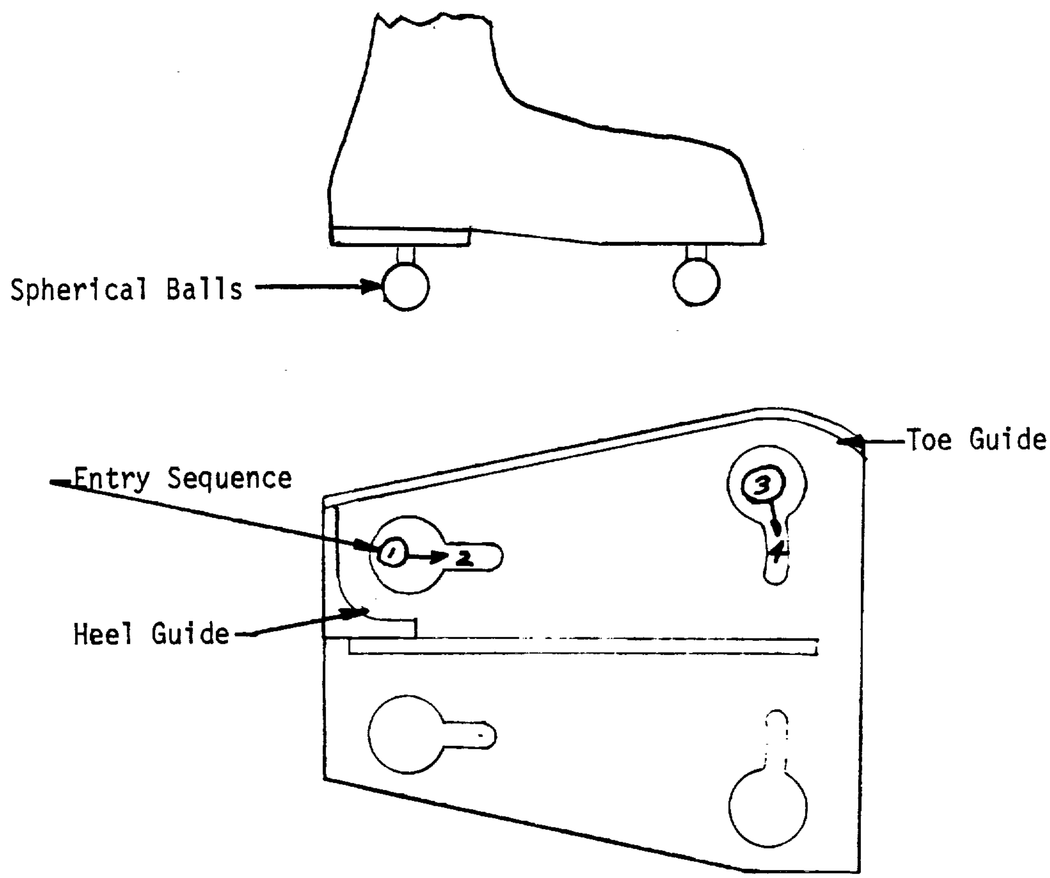
- Not a blind entry

Limitations: - Bladder leakage

- Expendable gas (GN_2)

FIGURE 3-2

INFLATABLE BLADDER FOOT RESTRAINT



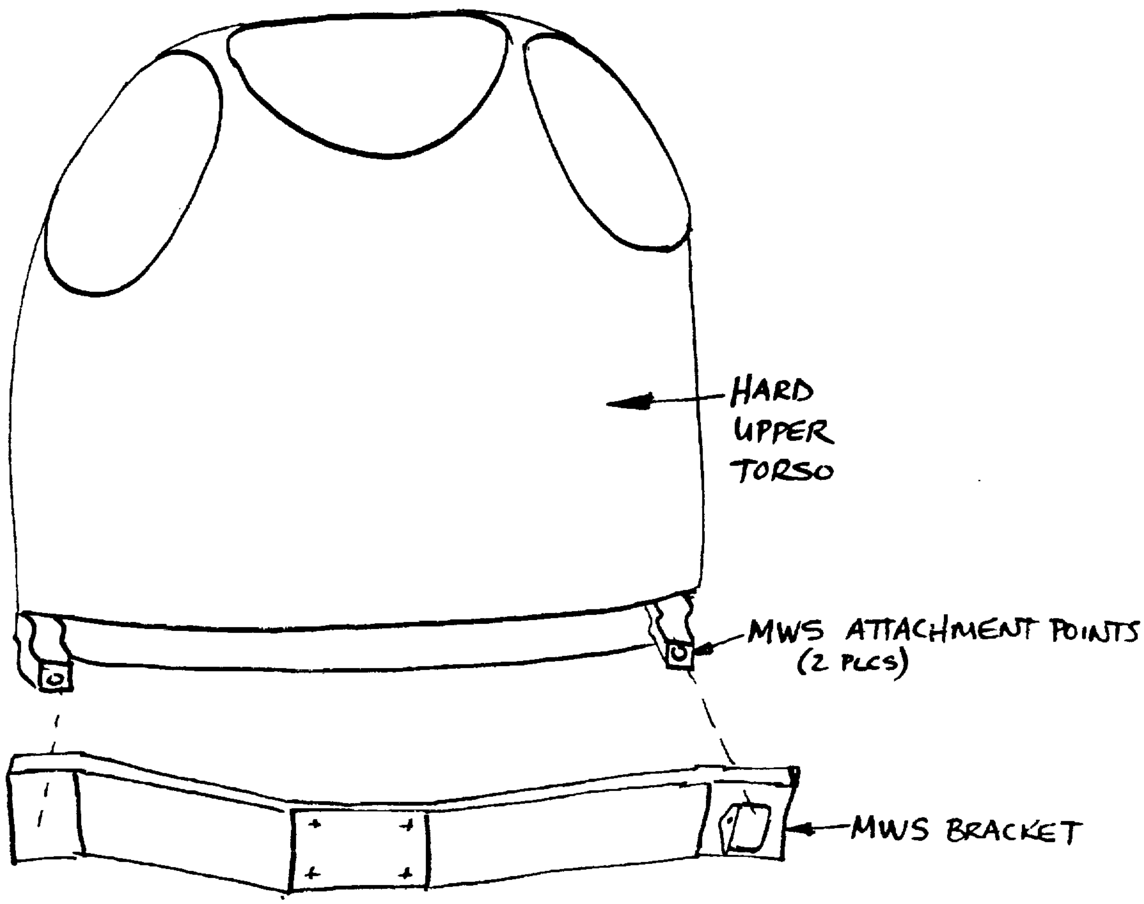
Advantages: - Restraint shaped to guide foot entry

- Balls not as great an impact potential as heel spur

Limitations: - Complicated ingress/egress motion

FIGURE 3-3

"KEYHOLE" ENTRY FOOT RESTRAINT

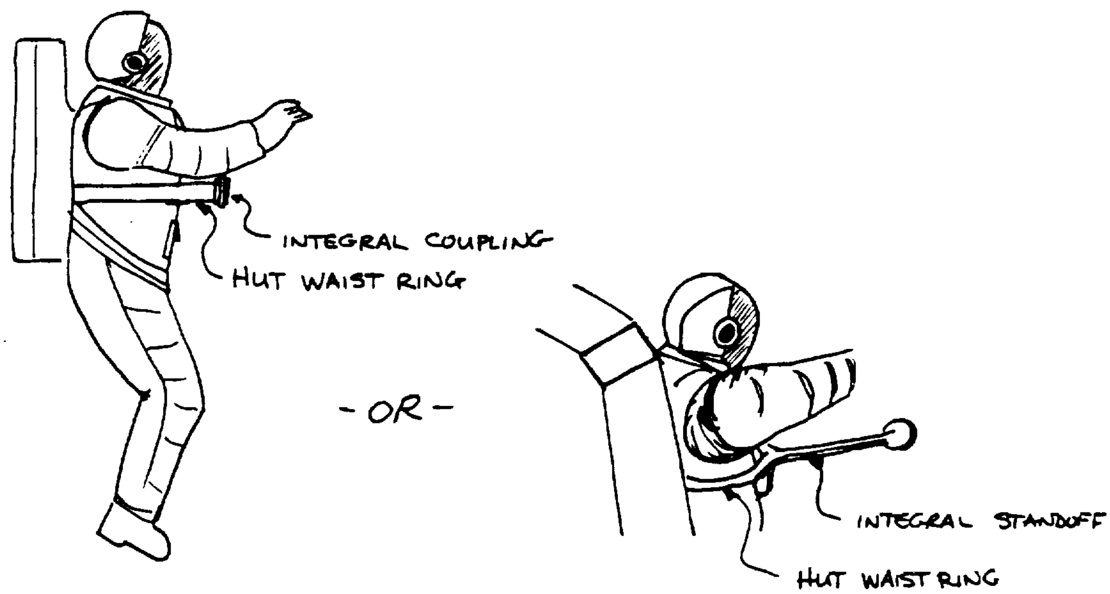


Advantages:
- Close to C.G. of crewman
- Reduced bending moment as compared to foot restraint
- Good position for controls

Limitations:
- Load limits on present HUT design

FIGURE 3-4

HUT ATTACHMENT AT MINI WORKSTATION POINTS



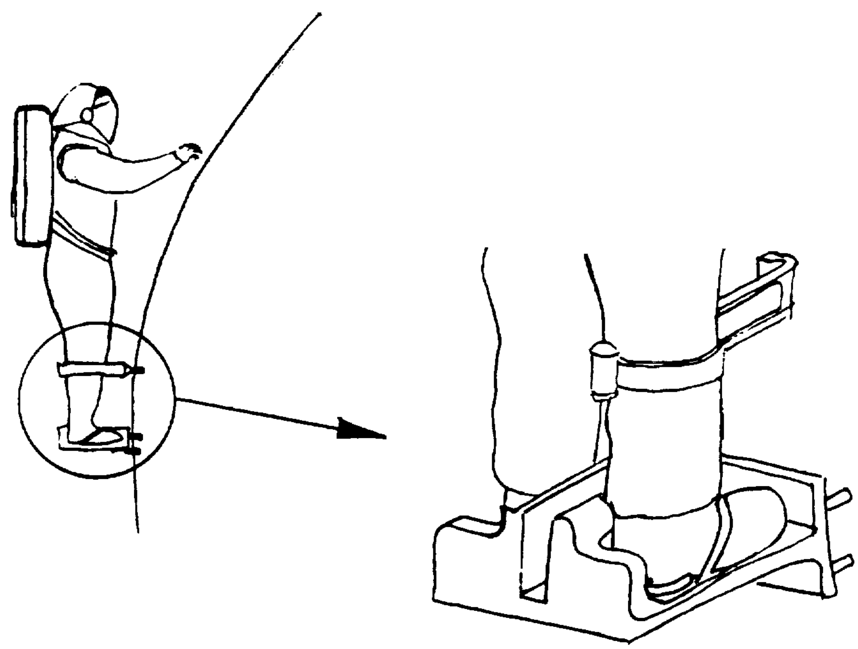
Advantages: - Waist attachment close to C.G.

- More easily reacts loads from arms
- Redesign of HUT could provide greater load capabilities

Limitations: - Requires redesign/modification of HUT

FIGURE 3-5

INTEGRAL HUT WAIST RING



Advantages: - Allows bending of legs at knees for minor positional adjustment

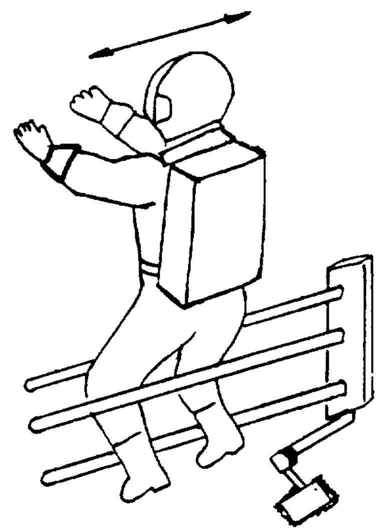
- Lightweight and simple

Limitations: - Must egress to relocate

- No adjustment up/down

FIGURE 3-6

TOE/LEG RESTRAINT



Advantages: - Ease of ingress/egress

- Simplicity

Limitations: - Limited adjustment in place

- Requires extension of legs to maintain restraint

FIGURE 3-7

KNEE BRACE "TRI-BAR" RESTRAINT

The initial emphasis had been to investigate crewman attachment to areas that are not designated as scheduled work or maintenance sites - in other words - emergency EVA repair sites. Two major types of attachments were studied:

1. Mechanical clamping onto various cross section beams using over-center type clamps. The other end of the adapter would be the standard GWS interface.

2. Adhesive bonding to a structure which does not permit clamping (i.e., flat panel) may be accomplished by bonding an attachment device to the structure. Several adhesives were evaluated and the results do not look promising, however, these were commercially available and there are some suppliers that may be able to formulate an adhesive that would perform adequately. The development of a space adhesive could become a program in itself.

The adhesives investigated were:

Name	Type	Remarks
Permabond 910	Cynoacrylate	Approximately 2 minute cure, brittle at low temperature. Requires surface moisture to begin cure
Loctite 324	Anerobic	Requires application of light pressure
Abelfilm 542	Microwave	Dry film adhesive - requires light pressure and high temperature (>350^{o}F)
Loctite Shadoware 361	U.V.	Contains solvent, requires part that allows transmission of UV, not gap filling

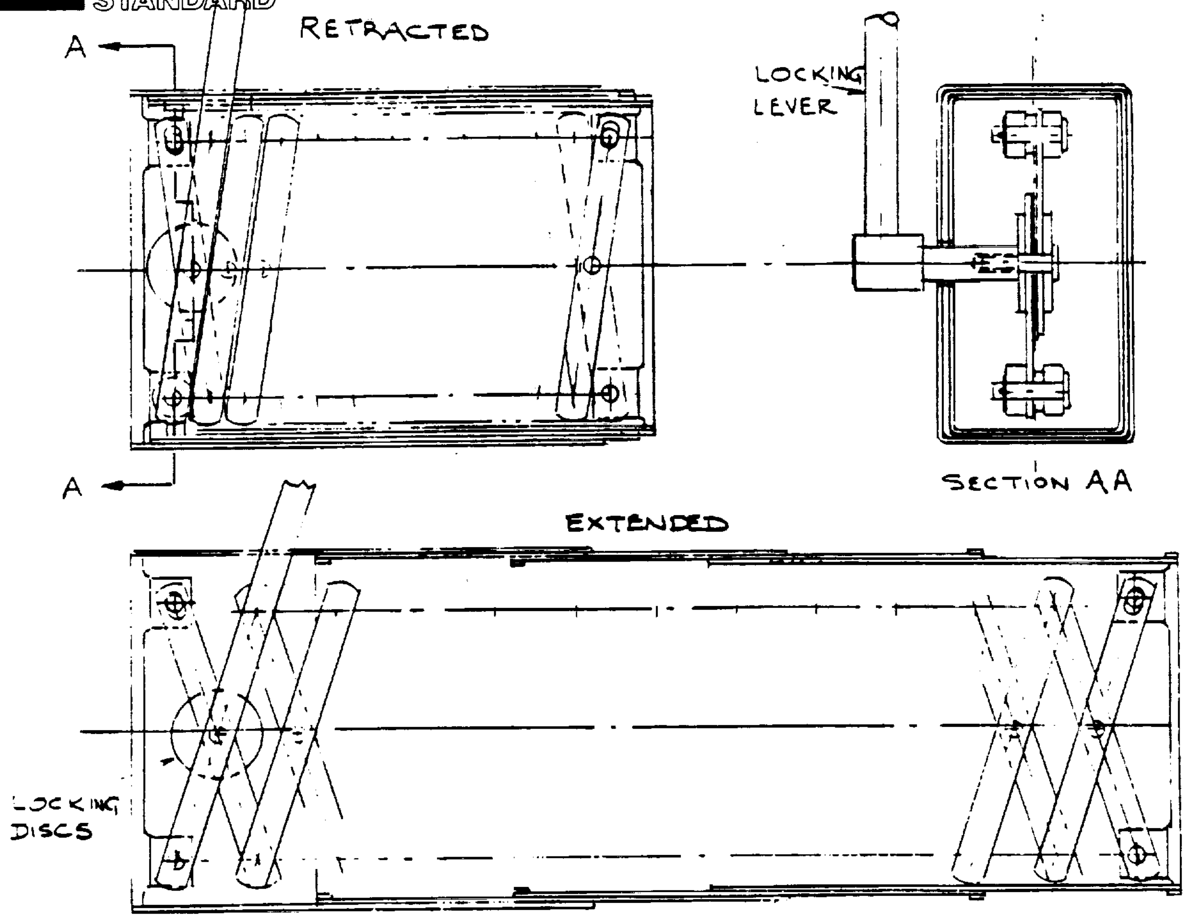
Shear tests were performed on samples of each adhesive listed above and preliminary results indicate that a specially formulated adhesive will be required in order to provide the strength to react the design limit of 100 pounds and the associated bending moment of 400 ft-lbs. The most promising adhesives have excellent tensile and shear properties, but with peel strengths on the order of 8 pounds per inch, the pad size would be approximately 34" x 34".

Adjustment Mechanism

In addition to the crewman and structure interfaces, the final portion of the system was the means to adjust the crewman position at the worksite.

Several adjustment mechanisms were investigated including:

1. Telescopic boom (Figure 3-8)
2. Mechanical arm (Figure 3-9)
3. Slide bar (Figure 3-10)



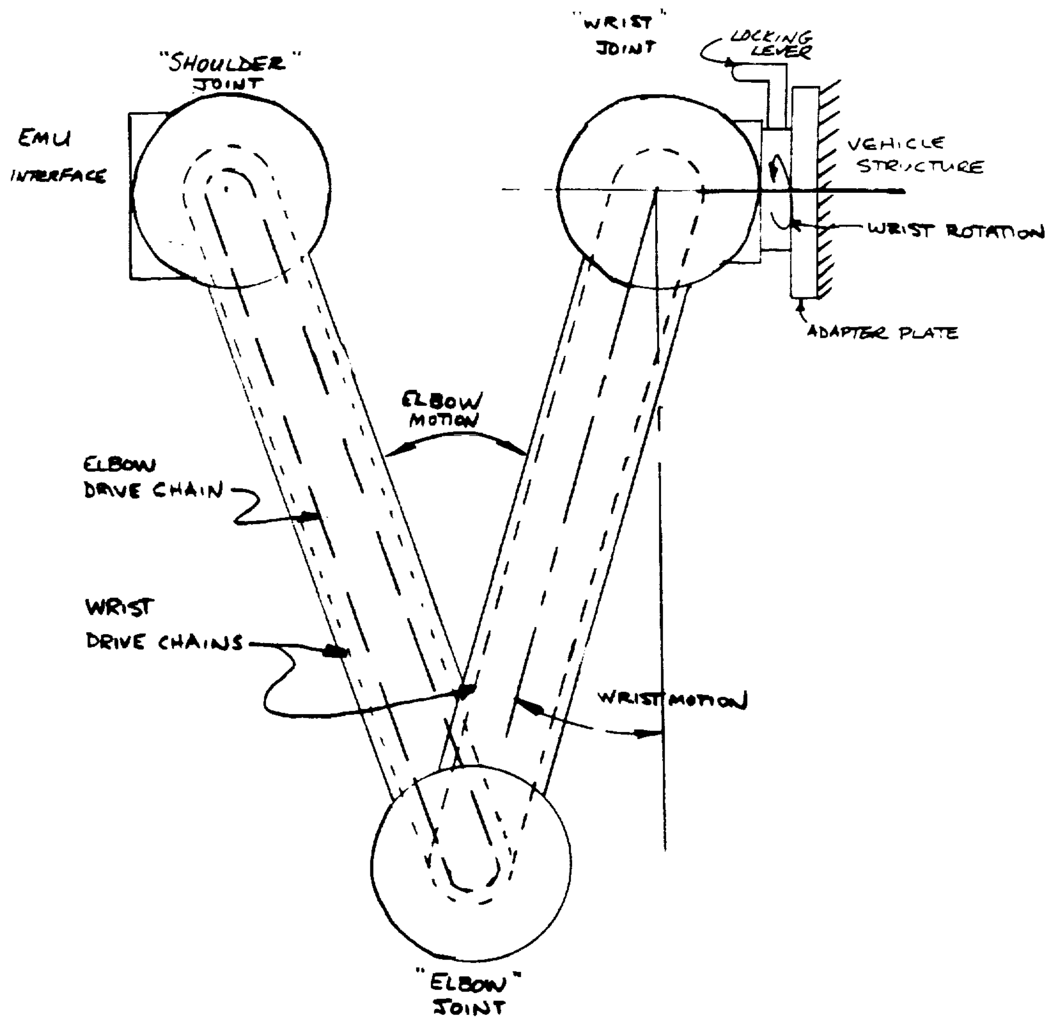
Advantages: - Simple push/pull motion

Limitations: - Requires pivot/rotation at both ends

- Mockup indicated tolerance problems with scissor linkage

FIGURE 3-8

TELESCOPIC BOOM



Advantages: - Provides excellent positioning while in place

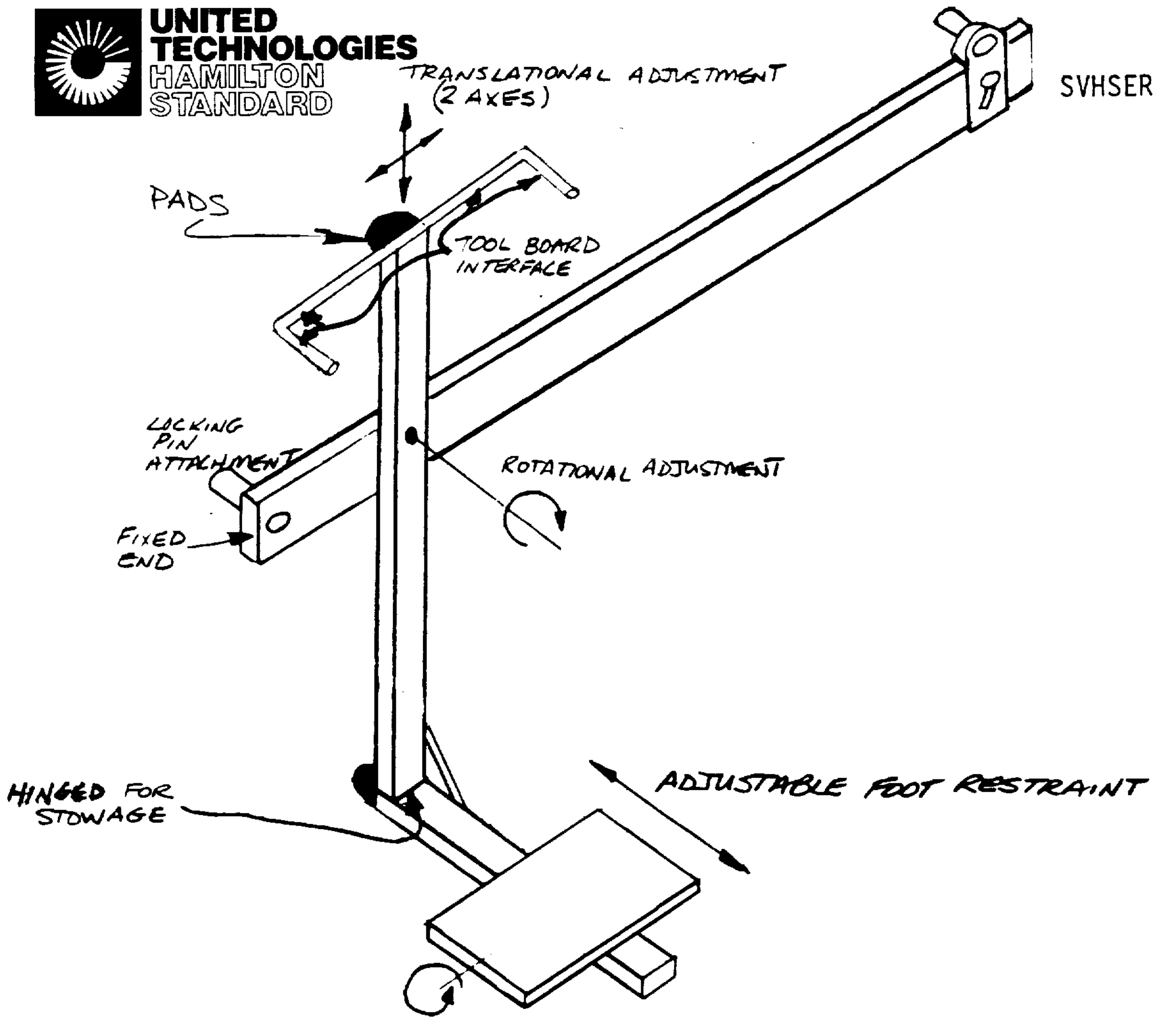
- Easily interfaces with EMU at waist

Limitations: - Weight

- Can interface with foot restraint but controls need to be placed within sight and reach (near waist)

FIGURE 3-9

DRIVEN ELBOW



Advantages: - Large working area

Limitations: - Large size

- Favors large flat surfaces

FIGURE 3-10

SLIDE BAR RESTRAINT SYSTEM

Adjustment Mechanism (continued)

The telescopic boom was a series of rectangular cross-sectioned tubes which were extended and retracted by a series of scissor-type linkages. A mock-up of this adjustment mechanism was built to evaluate the possibility of tolerance problems on the multiple linkage. An excessive amount of play was present and this concept was dropped from further consideration. The mechanical arm concept consisted of a two arm linkage with pivots at the center and each end. One end has an attachment device which interfaces with the EMU and a control box to drive the other two joints. The pivot point at the EMU is referred to as the shoulder joint. The second and third joints, referred to as the elbow joint and wrist joint, are driven from the control box with separate handles. As all of the pivoting is in the same plane, rotation is needed at the wrist joint. Wrist rotation provides the system with an essential third degree of freedom which not only permits adjustment toward and away from the surface, but also full rotation about the attachment point. This system appears to be the most versatile and workable.

Concept Selection

A preliminary Concept Review Meeting was held with the NASA technical monitor in June of 1984 where several concepts were identified as ones to pursue.

The concept chosen for fabrication of a test unit was the mechanical arm with a combined waist and foot restraint. The wrist rotation feature will be built into the working model.

The original intent was to build and evaluate two concepts - a foot restraint and a mid-body/waist restraint, and compare them in a manned WETF evaluation.

The two concepts were able to be integrated into one piece of hardware. Not only did this reduce fabrication costs but also allowed use of the system as a combined foot and waist restraint.

IV. WORKING MODEL

Discussion

The working model was designed to evaluate drive ratios and restraint concepts in a neutral buoyancy environment. Several features were designed specifically for WETF in order to reduce the complexity and cost of the test hardware. The GWS concept chosen for fabrication and WETF evaluation was the chain driven mechanical arm with waist and foot restraints (Ref. Figure 4-1 and 4-2). The system can be described as a mechanical arm with its shoulder pivot being attached to the astronaut's waist, an elbow joint and a wrist joint. The shoulder pivot is manually activated once the locking clamp bolts are loosened by the diver. Following manual positional adjustment, the clamp bolts are tightened by the diver and the joint is locked in place.

The elbow joint is adjusted by first loosening clamp bolts, turning a crank at the control box mounted at the waist until the desired position is reached, and tightening the clamp bolts. The crank torque is transmitted to the elbow via chain and sprocket. Sizing of the sprockets can provide a variety of drive ratios. The speed ratio selected for WETF testing was 4:1 at the elbow joint and up to 10:1 at the wrist joint. The WETF test was performed with a 4:1 reduction at the elbow and 5:1 at the wrist-pivot. It should be pointed out that wrist rotation was not included in this model as the drive ratio required to operate the wrist is the same as that required to operate a rotational wrist joint. The next generation GWS has wrist rotation and locking without the aid of a diver.

The wrist joint is the end which attaches to the work site. The present attachment device is a handrail clamp originally used by ILC/CLC for their WILT tool.

The GWS uses a modified Shuttle foot restraint where the left and right foot positions are reversed. This was done for two reasons - 1) to clear the down-tube which, for balance reasons, was placed between the feet and, 2) sliding the heals outboard to egress seemed a more natural motion and allows both heels to be moved simultaneously without interference. Although the heel entry is unchanged (still a blind entry), this configuration will continue to be used until a better foot restraint can be developed.

WETF Testing

The GWS working model was subjected to WETF testing at MDAC Huntington Beach, on June 7, 1985. Several hardware problems prevented the performance of the test with a suited subject, but information was obtained that aided in the design of the Feasibility Test Unit.

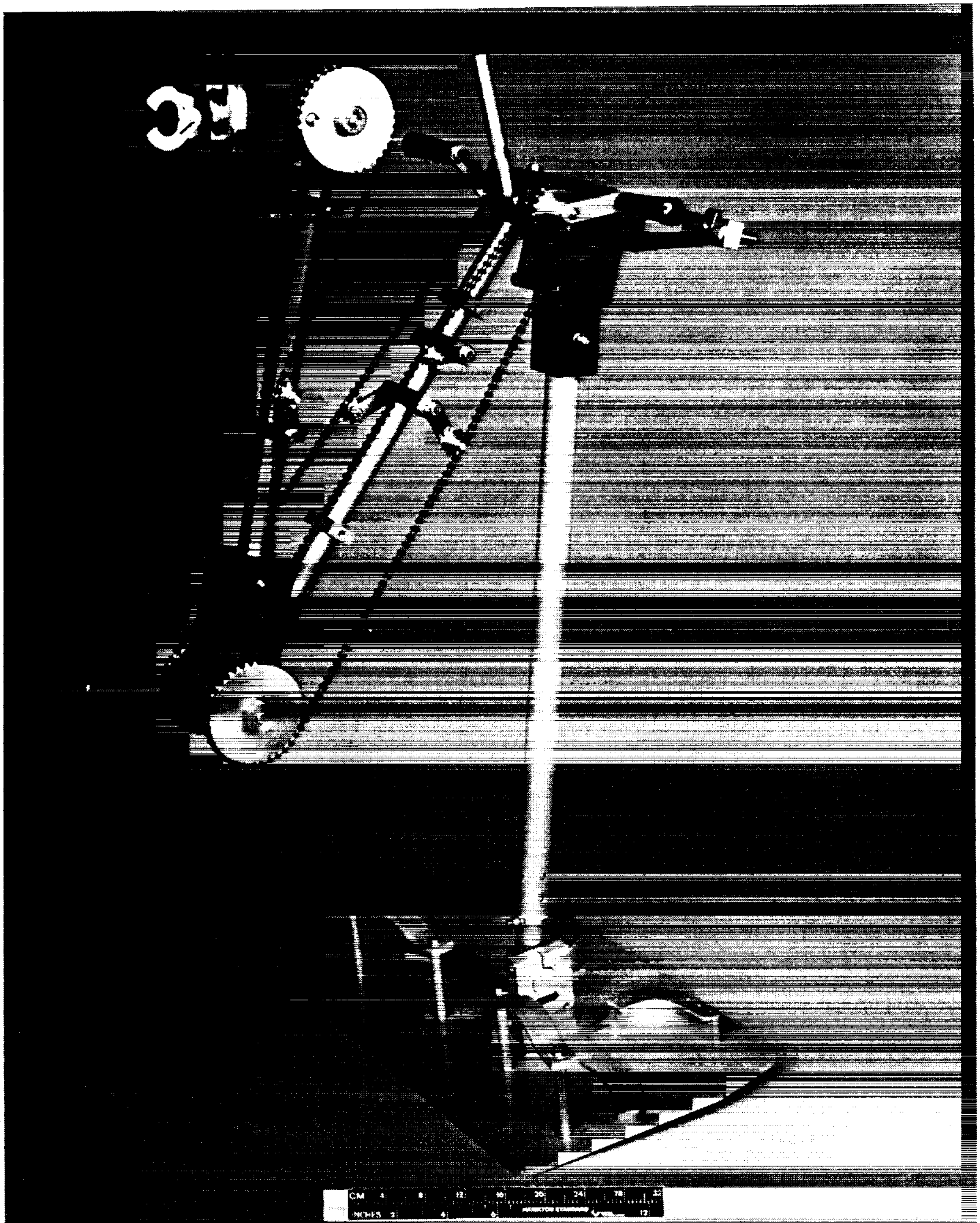


FIGURE 4-1

GWS WORKING MODEL

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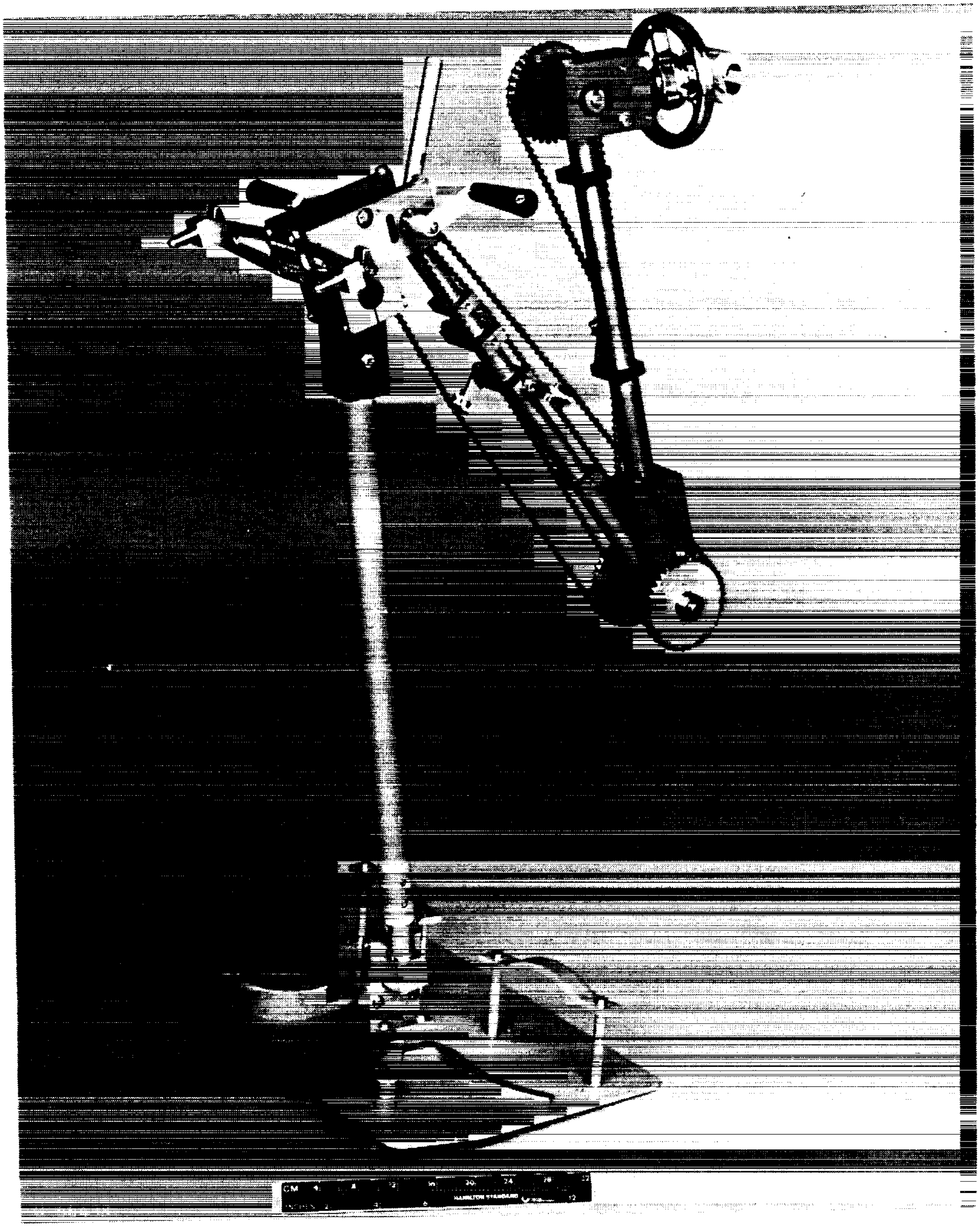

FIGURE 4-2

GWS WORKING MODEL

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WETF Testing (continued)

The GWS was clamped to a handrail in about fifteen feet of water. The test subject attempted to drive each of the joints individually with no success. In an effort to get one joint moving, the test subject overstressed a drive pin and sheared it. The pin was repaired and the test was again attempted with a a new test subject. The new test subject experienced the same difficulty in moving any joint and began applying excessive loads on the hand crank. The resultant higher tension caused the chain idler to slip. In addition, the retaining collar on the hand crank shaft slid approximately .050" which resulted in bending of the other drive pin due to a concentration of loads at the end of the drive pin.

Several observations were made during the testing of the GWS:

1) Neutral buoyancy is extremely difficult to achieve on a dynamic system. The GWS can be balanced in a particular position, but it may resist a change in orientation. In addition, buoyancy control of a scuba diver is difficult because the suited diver's displaced volume changes during ascent and descent, and even during normal breathing. The GWS was designed to provide a 5 pound force at the end of the arm. If the diver and hardware are not properly balanced, he will not be able to generate the torque required to move the GWS.

2) Friction in the system turned out to be much higher than anticipated. Much of this friction was caused by bending loads on the shaft due to the chain tension. In a one-g evaluation following the WETF test, the force required to move the arm with and without the chains installed was compared. One pound is required to move the arm without the chains installed; four pounds are required when the chains are in place. This increase in friction is due only to chain tension and further increases when the crank is actuated as this increases the chain tension.

3) The importance of test subject familiarity with the hardware and its proper operation cannot be stressed enough. Although the test subjects received a briefing before the test, it became apparent that the briefing was not enough. More time will be spent to train the test subject prior to the next test.

4) Wrist rotation is essential in the Feasibility Test Unit. By providing wrist rotation as well as wrist, elbow, and waist pivoting, the GWS will have three degrees of freedom, be capable of providing a four foot radius arc around the attachment point, and have adjustment towards and away from the surface. In addition, the system must be lockable without the need of a diver to loosen and tighten bolts.

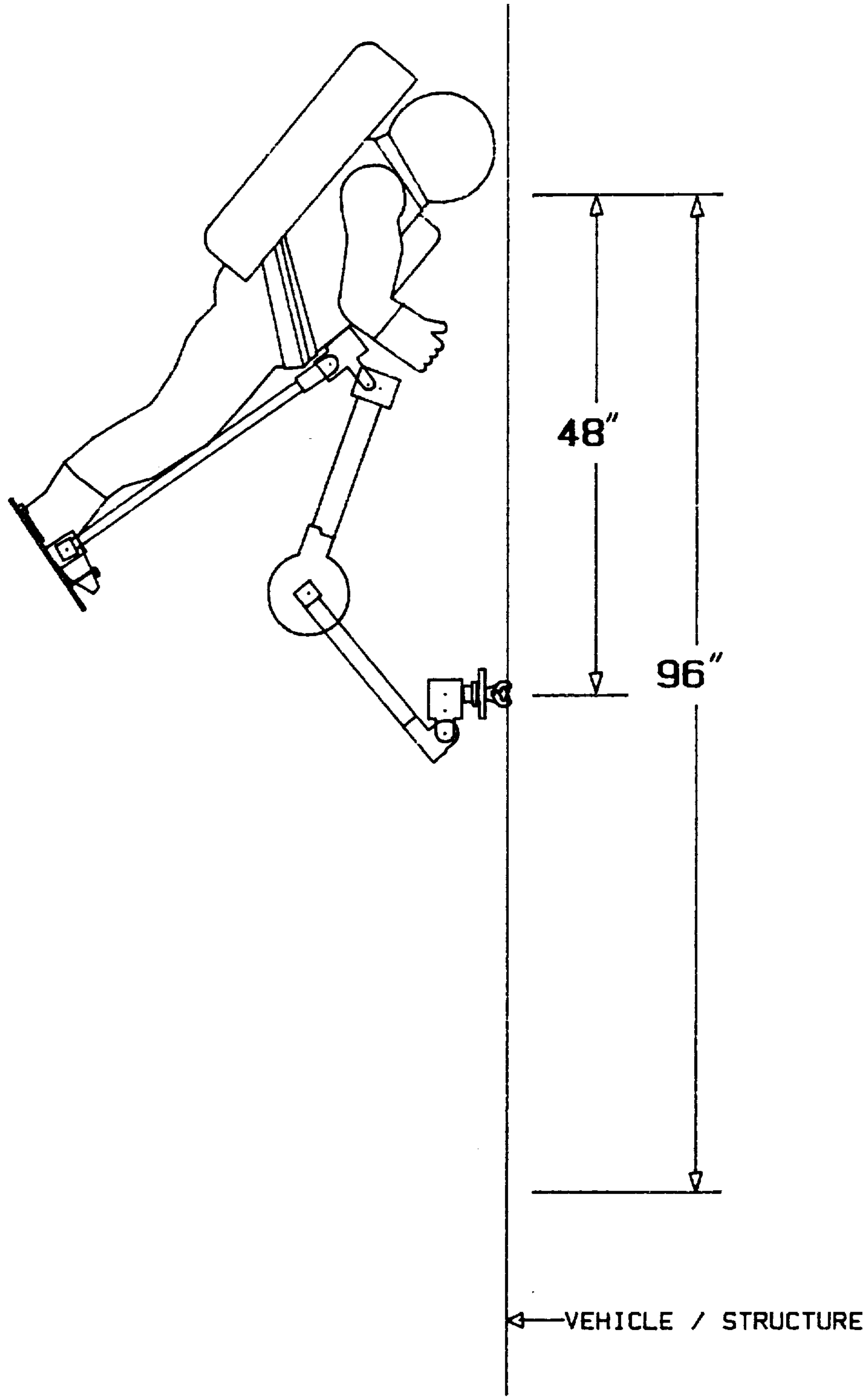

FIGURE 5-3
GWS REACH ENVELOPE

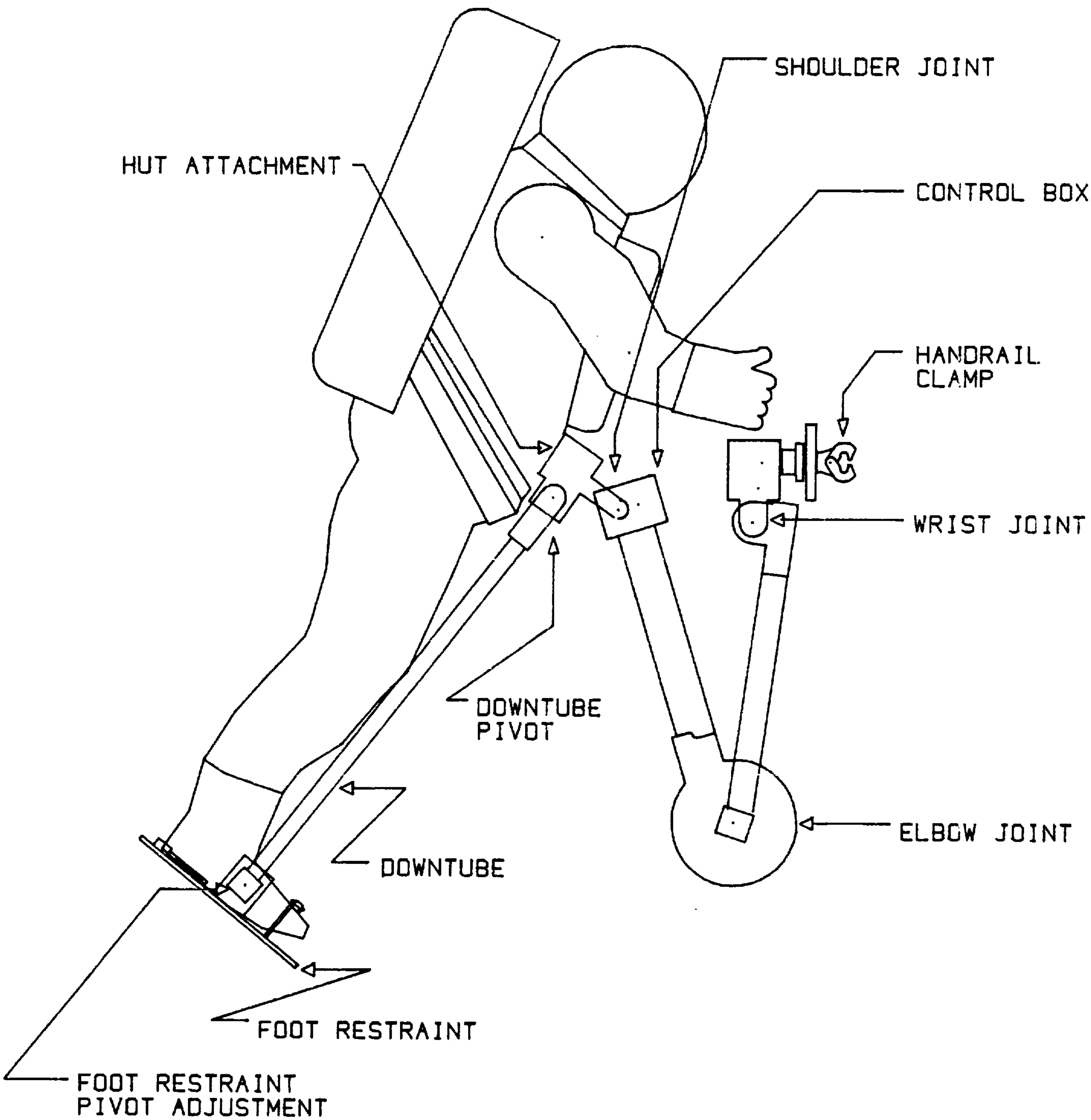

FIGURE 5-4

MAJOR COMPONENTS OF THE GWS

V. DESIGN UPDATE

Hardware Redesign - Feasibility Test Unit

As a result of the difficulties encountered during testing and the need to incorporate locking joints, a rotating wrist, and increased mechanical advantage, the mechanical arm was completely redesigned. In order to lock each joint, two methods were investigated. The first involved a braking system with a locking lever for each joint. This was considered bulky and complicated as each motion would require unlocking the joint using an actuating lever, cranking the handcrank until the desired position is reached, and finally actuating the locking lever. The second method makes use of a worm gear drive which does not allow itself to be backdriven. This eliminates the need for a braking system and reduces the complexity of operation as each adjustment is accomplished with the turn of a single crank.

In order to reduce friction and increase mechanical advantage, the chain and sprocket drive system has been replaced by a gear drive system. The gears and shafts are all enclosed as compared to the external chains and sprockets of the previous model (Ref. Figures 5-1 and 5-2).

Wrist rotation was incorporated into the new model and is self-locking via a worm gear in the final drive. The wrist motions (pivot and rotation) share a common input shaft and hand crank, with a lever to select which output is desired. The speed ratio for both wrist motions is 80:1. The elbow pivot has only half the moment arm as the wrist, therefore a 40:1 reduction has been selected.

The basic dimensions remain the same with two foot arms which give the EVA crewman a four foot radius arc or eight foot diameter circular work envelope about a single attachment point (Ref. Figures 5-3 and 5-4).

In summary, several improvements have been made in going to a gear driven system: 1) The drive system is more compact and can be enclosed in a relatively simple housing. 2) The system is now self-locking which simplifies operation. 3) The wrist pivot torque ratio has been increased from 3:1 to 15:1. 4) The addition of wrist rotation completes the system, providing the necessary third degree of freedom.

One-g Test

The mechanical arm was attached to a handrail and oriented on its side to minimize the effects of gravity. The cranks were actuated and the wrist and elbow pivots functioned properly. Some binding in the wrist pivot was noted but was attributed to the arm not being parallel to the ground. Once the position was readjusted, both pivoting joints were acceptable. The elbow joint was experiencing more drag than the other two joints but the unit was left in that condition for neutral bouyancy testing.

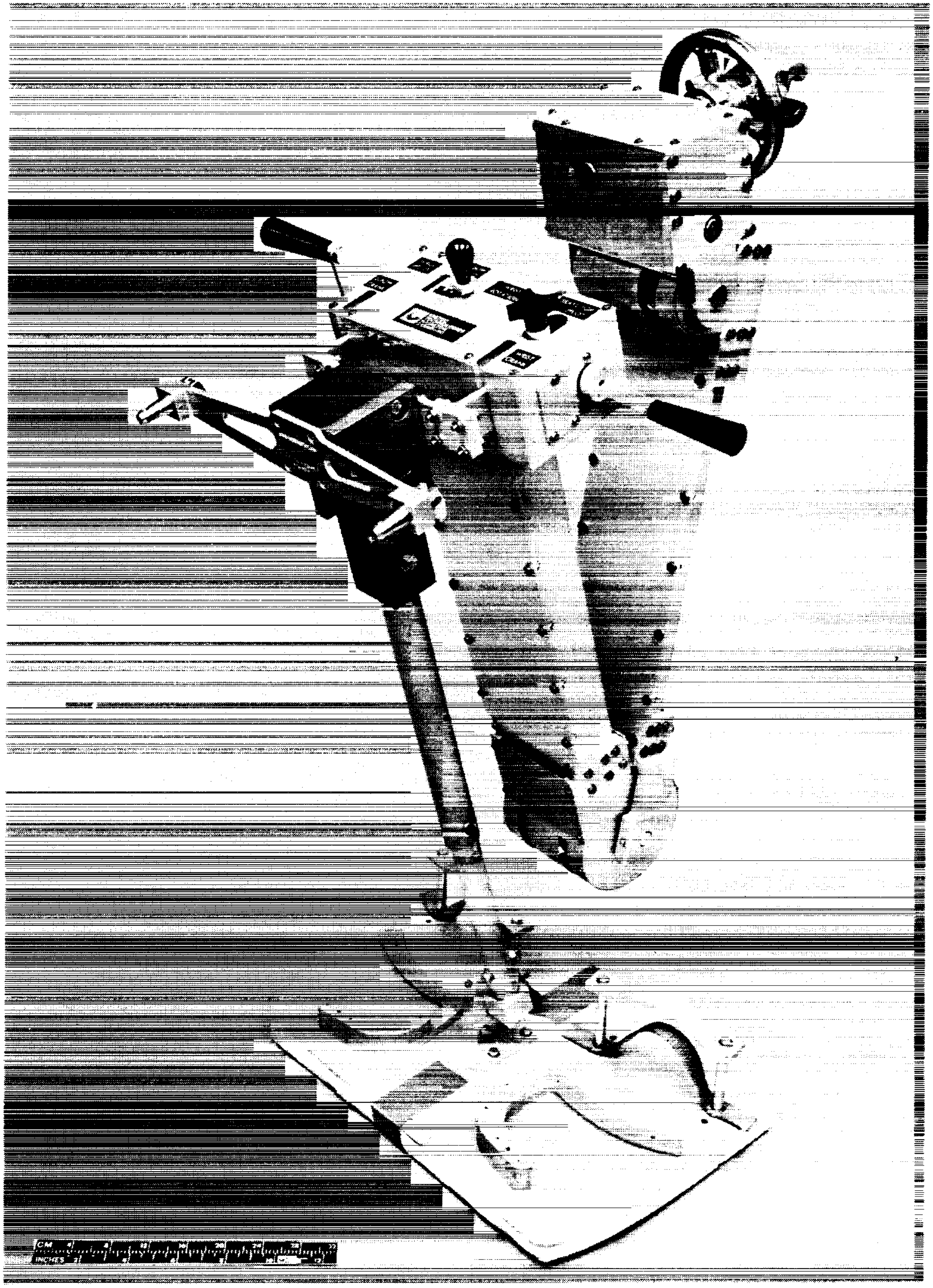

FIGURE 5-1

GWS FEASIBILITY TEST UNIT

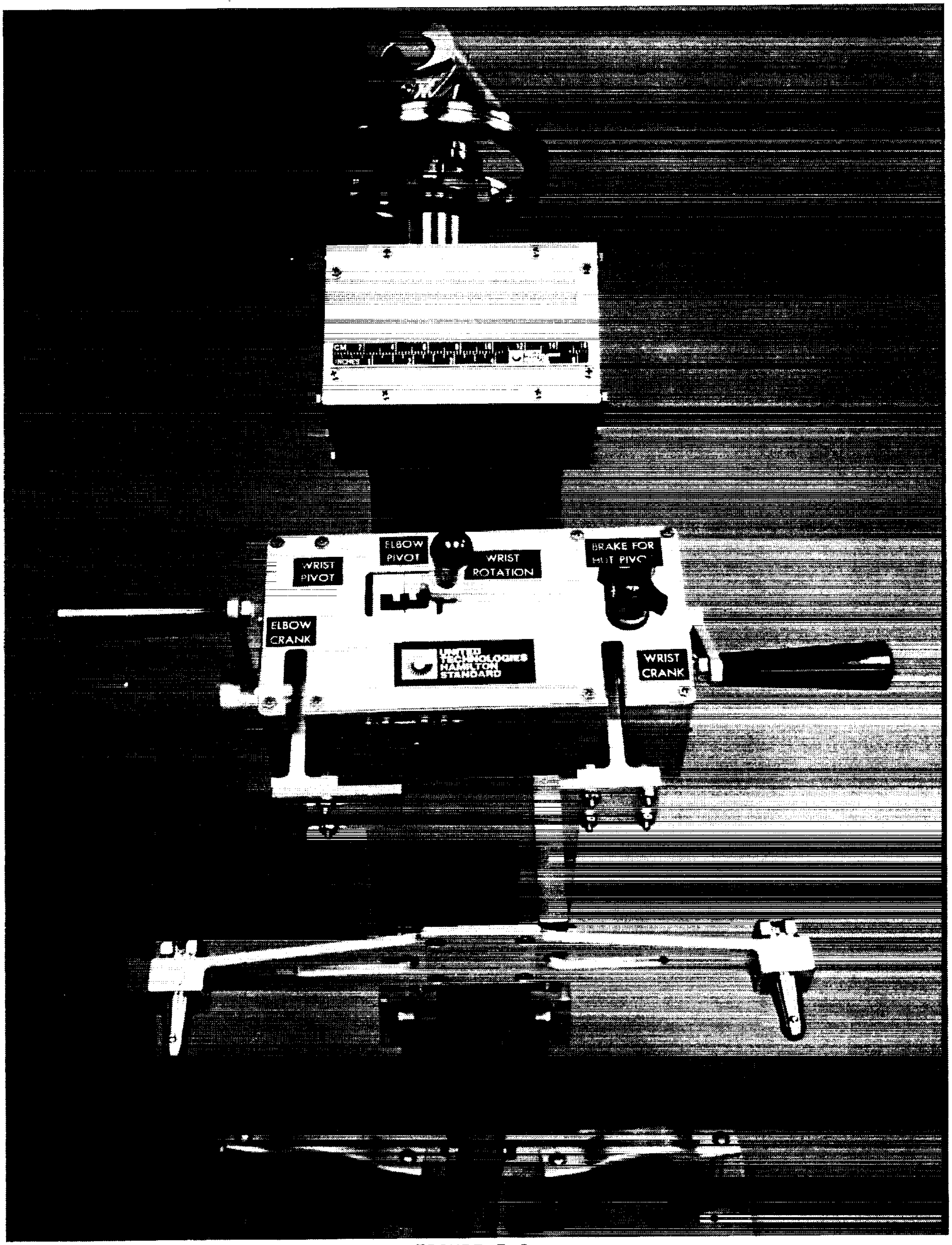

FIGURE 5-2

GWS FEASIBILITY TEST UNIT
VIEW FROM CREWMAN POSITION

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One-g Test (Continued)

The arm was then rotated 90° so that the gears had to lift the arms or pivoting ends. This provided too much load in 1-g which was to be expected as the unit was not made to operate without assistance in 1-g.

Neutral Bouyancy

The feasibility test unit was subjected to neutral buoyancy testing on July 19, 1986. Foam panels were taped in various locations to make the test unit as neutrally buoyant as practical. It is important to note that this is a dynamic system and it is difficult to neutralize the system in all attitudes. The arm was neutralized at 180° and 90° with the clamp end supported. The arm was then clamped onto the handrail simulator. The foot platform was attached and minor adjustments were made to prevent the foot platform from sinking.

Prior to the test subject attaching himself to the foot restraint, each joint was activated "without loads" to assure that the unit was close to neutrally buoyant. All joints operated properly without the test subject attached.

The test subject then stepped into the foot restraint using the webbed strapping to secure his feet to the foot platform and a webbed belt around his back and tied to the MWS attachment bracket. Each joint was actuated and performed properly. The wrist rotation had some drag which was anticipated based on 1-g testing, but this was reduced by the test subject controlling his buoyancy more precisely. The wrist rotation drive was adjusted after testing to reduce frictional losses.

Results of Testing

- o All joints performed properly with minimal frictional losses.
- o Gear ratios are adequate.
- o Worm gears provided good system locking.
- o Combined foot restraint/soft waist attachment had good feel.
- o Buoyancy critical for smooth operation.

Hard mount at waist could not be evaluated in scuba. If an evaluation is planned with a WETF EMU, the foot restraint should be removed as otherwise, the suited subject may overload the HUT ring.

VI. BOUYANCY AND OPERATING INSTRUCTIONS

A. Buoyancy Considerations

As this is a dynamic system, neutral buoyancy must be attained in various attitudes. The following method was used to balance the GWS:

1. The arm was extended and the foot restraint and down-tube removed. One diver held the adjusting ring near the handrail clamp and the other end was left free to rise or sink in the water. Foam was added until the arm was close to neutrally buoyant on (Ref. Figure 6-1).

2. The elbow joint was rotated 90° and checked again laying on its side. A small amount of foam was placed on the elbow pivot points and a smaller amount removed from the control box area. (Ref. Figure 6-2).

3. The foot restraint down-tube was adjusted to the height of the test subject, neutralized, and installed. (Ref. Figure 6-3).

B. GWS Operating Instructions

CAUTION

This hardware is made for operating in WETF only. Attempted operation in 1-g may result in damage to the mechanisms.

Refer to Figures 6-4 to 6-6 In the following discussion.

1. Attach the handrail clamp to the handrail by turning the adjusting wheel clockwise (as viewed from the control box) until the clamp is tightened.

2. Test subject should be neutrally buoyant.

3. Adjust the down-tube and foot pivot angles using a 1/2" wrench. Each of these pivots are adjustable for leg length and test subject preference.

4. Step into foot restraints (webbed straps are for scuba and must be removed if an EMU suited subject is to be used).

5. Use of waist restraint in scuba helps maintain proper body position. A piece of webbed strapping wrapped around the waist attachment bracket, passed around the test subject's back, and secured at the waist attachment bracket provided sufficient support yet was easily removable.

6. Waist pivoting is accomplished by:

   a. Loosening a brake for "HUT PIVOT" knob.
   b. Pushing off or pulling on control box to elbow joint arm using leg or hand.
   c. Tightening knob once in desired position.

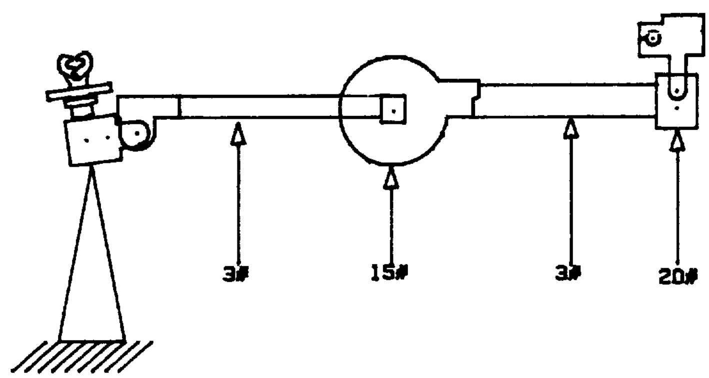

FIGURE 6-1

APPROXIMATE BUOYANCY REQUIREMENTS

WITH ARM AT 180 DEGREES

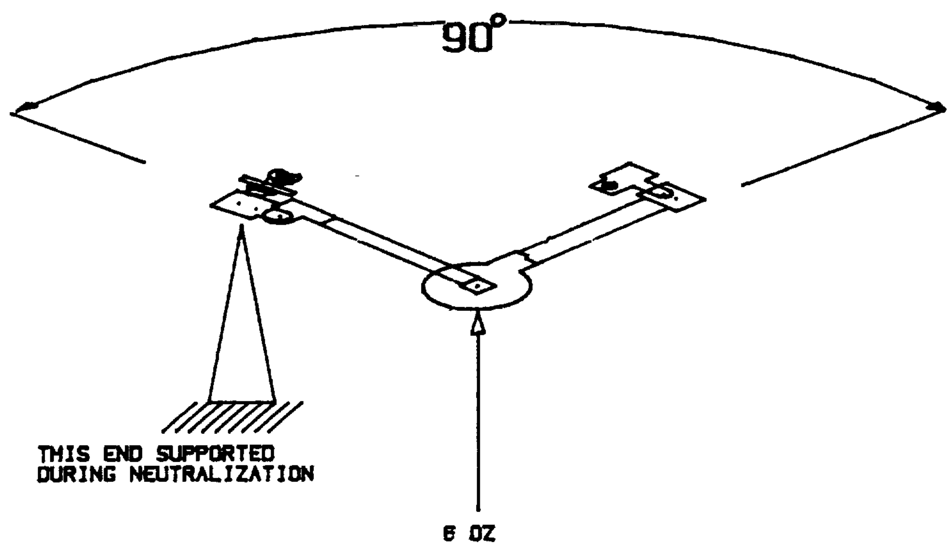

FIGURE 6-2

APPROXIMATE BUOYANCY CORRECTIONS
WITH ARM AT 90 DEGREES

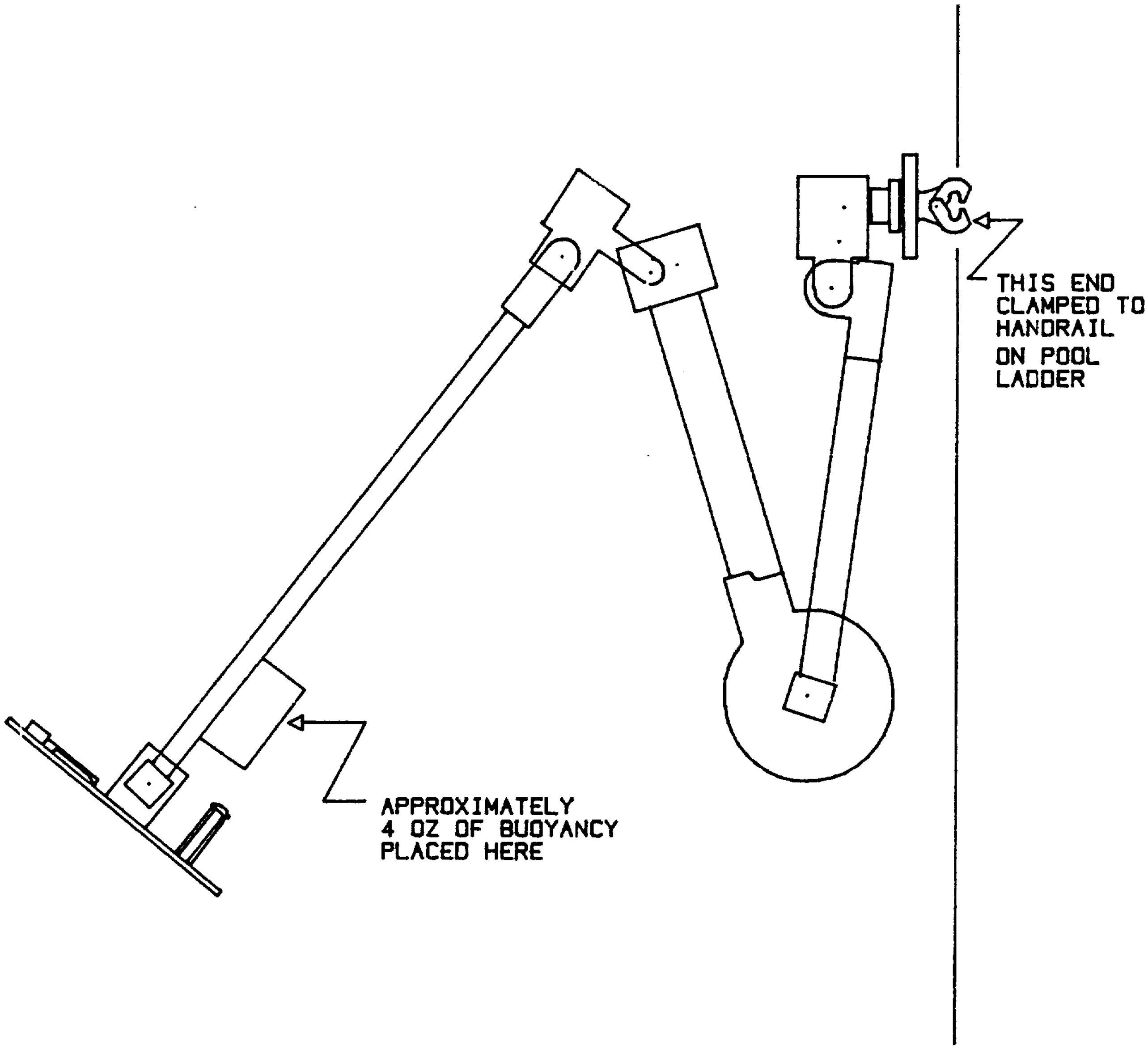

FIGURE 6-3

BALANCING THE FOOT RESTRAINT AND DOWNTUBE

B. GWS Operating Instructions (continued)

This pivoting motion allows the crewman or test subject to rotate forward, over the control box. The total range of adjustment is approximately 90°.

7. Elbow pivoting is accomplished by:

   a. Placing shift knob in center detent marked "ELBOW PIVOT". Failure to do so will allow gears to backdrive the wrist crank (Ref. Figure 6-4)

   b. Rotating left hand crank marked "ELBOW CRANK" until desired position is reached.

The elbow pivot is self-locking and closes to 25° and has approximately 260° of travel (although travel beyond 180° is not anticipated).

8. Wrist pivoting is accomplished by:

   a. Placing shift knob in left detent marked "WRIST PIVOT" (Ref. Figure 6-5)

   b. Rotating right hand crank marked "WRIST CRANK" until desired position is reached.

The wrist pivot is self-locking and has approximately 140° of travel.

9. Wrist rotation is accomplished by:

   a. Placing shift knob in right hand detent marked "WRIST ROTATION" (Ref. Figure 6-6).

   b. Rotating right hand crank marked "WRIST CRANK" until desired position is reached. Wrist rotation is self-locking and has continuous unlimited rotation.

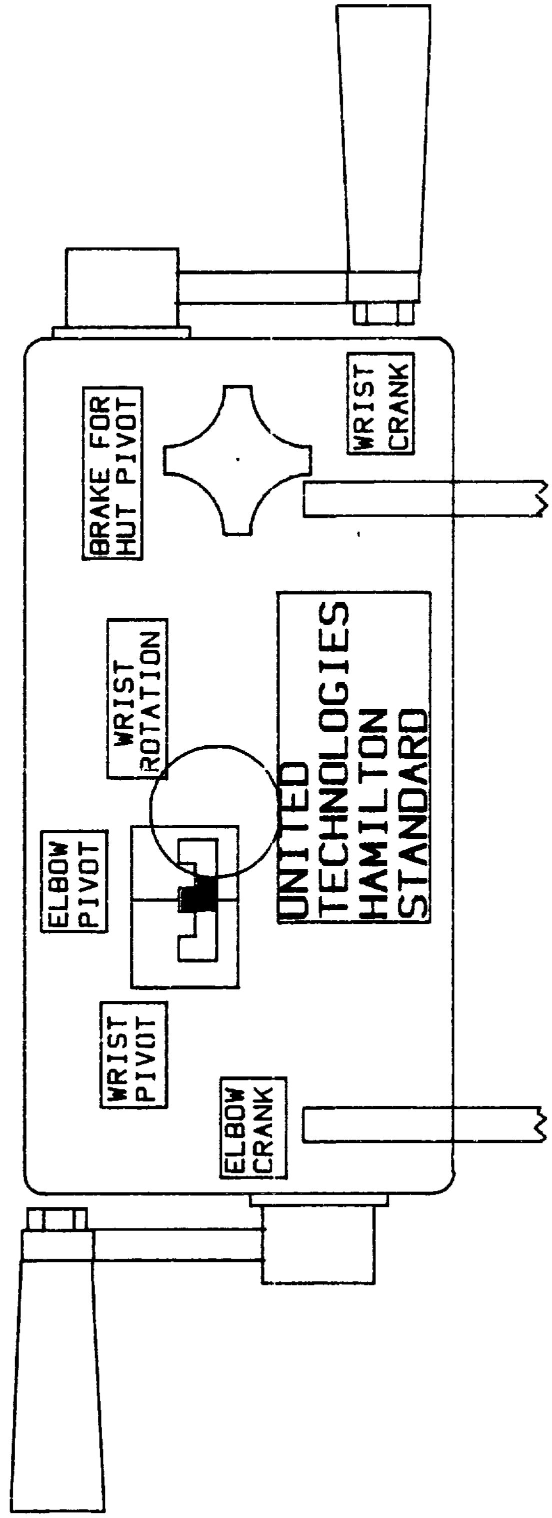

FIGURE 6-4
GWS CONTROL BOX SET FOR ELBOW PIVOT

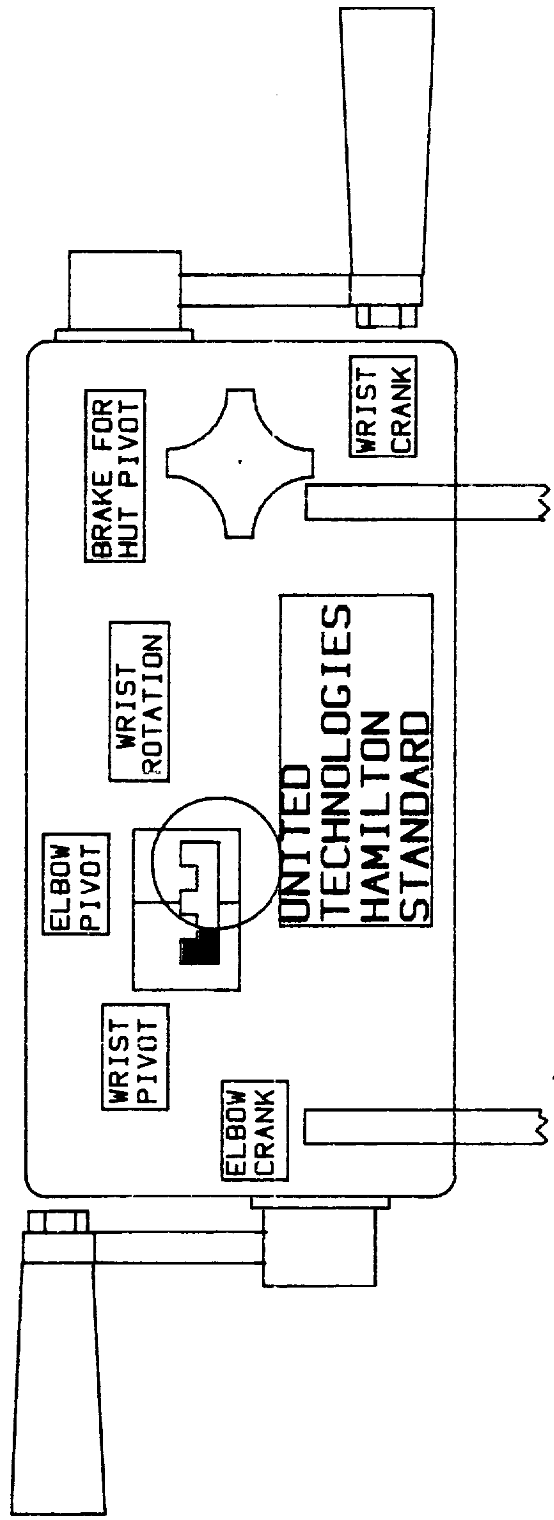

FIGURE 6-5
GWS CONTROL BOX SET FOR WRIST PIVOT

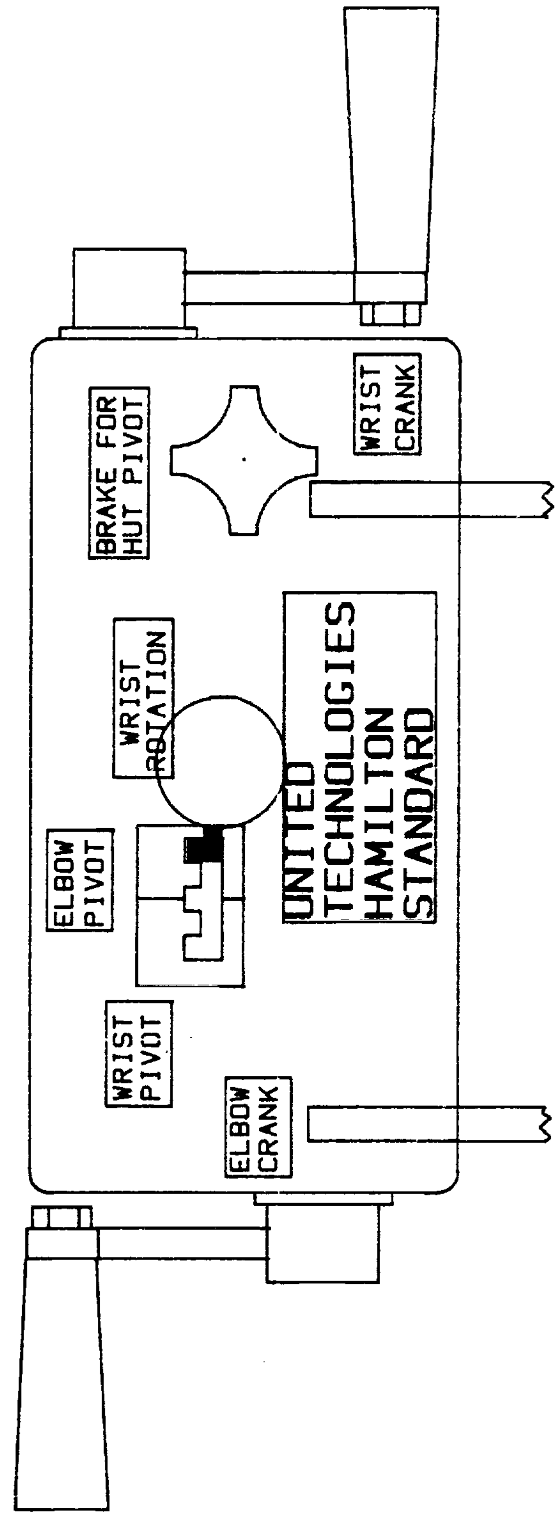

FIGURE 6-6
GWS CONTROL BOX SET FOR WRIST ROTATION

VII. INTERFACES

The present vehicle/structure interface is a handrail clamp designed and fabricated by ILC/CLC for their WILT tool (Ref. Figure 7-1). The clamp was shipped to NASA/JSC with the GWS hardware for evaluation purposes. The clamp attached to a standard Shuttle handrail by means of a threaded wheel driving the two opposing jaws together. The clamp threads into the rotating shaft at the wrist and a locking nut prevents inadvertent unthreading.

Although no formal design of a universal interface has been done, concepts are presented here with some design guidelines:

Using the NASA design requirement of 100 lbs. force in any direction, the interface would have to be able to react those loads. Due to the GWS configuration of a four foot arm, a resulting bending moment of 4800 in-lbs must also be able to be reacted. The interface must have flats or some means of indexing to prevent rotation of the interface itself. Single point attachment is important as it greatly reduces installation time and is less complex to operate.

The recommended interface is shown in Figure 7-2. It can easily be incorporated into the present GWS configuration by changing the wrist rotation shaft into an integral shaft and locking pin. The pin would be approximately 1.5 inches square and be six to eight inches long. The mating receptacle would be a square cross section hole approximately eight inches deep. This would permit almost flush mounting of the GWS wrist joint to the structure. For undesignated sites, a clamp type device with various interchangable jaws would have a similar receptacle to receive the square pin.

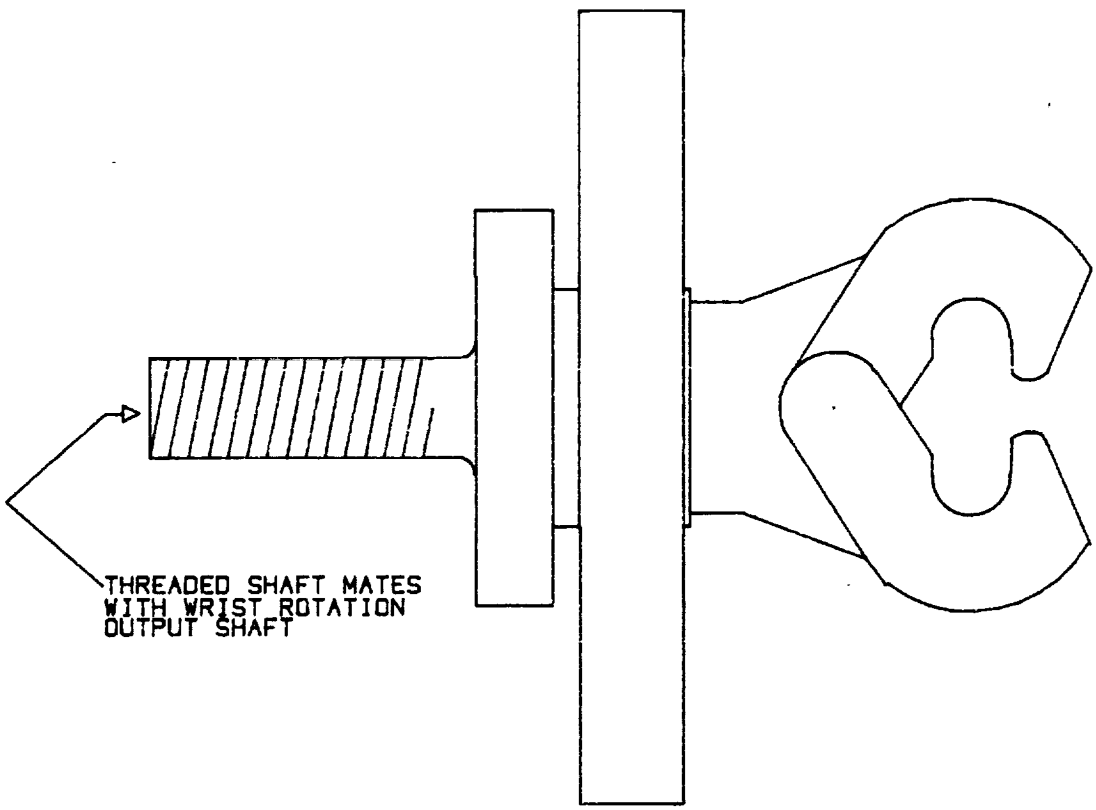

FIGURE 7-1

ILC WILT TOOL CLAMP

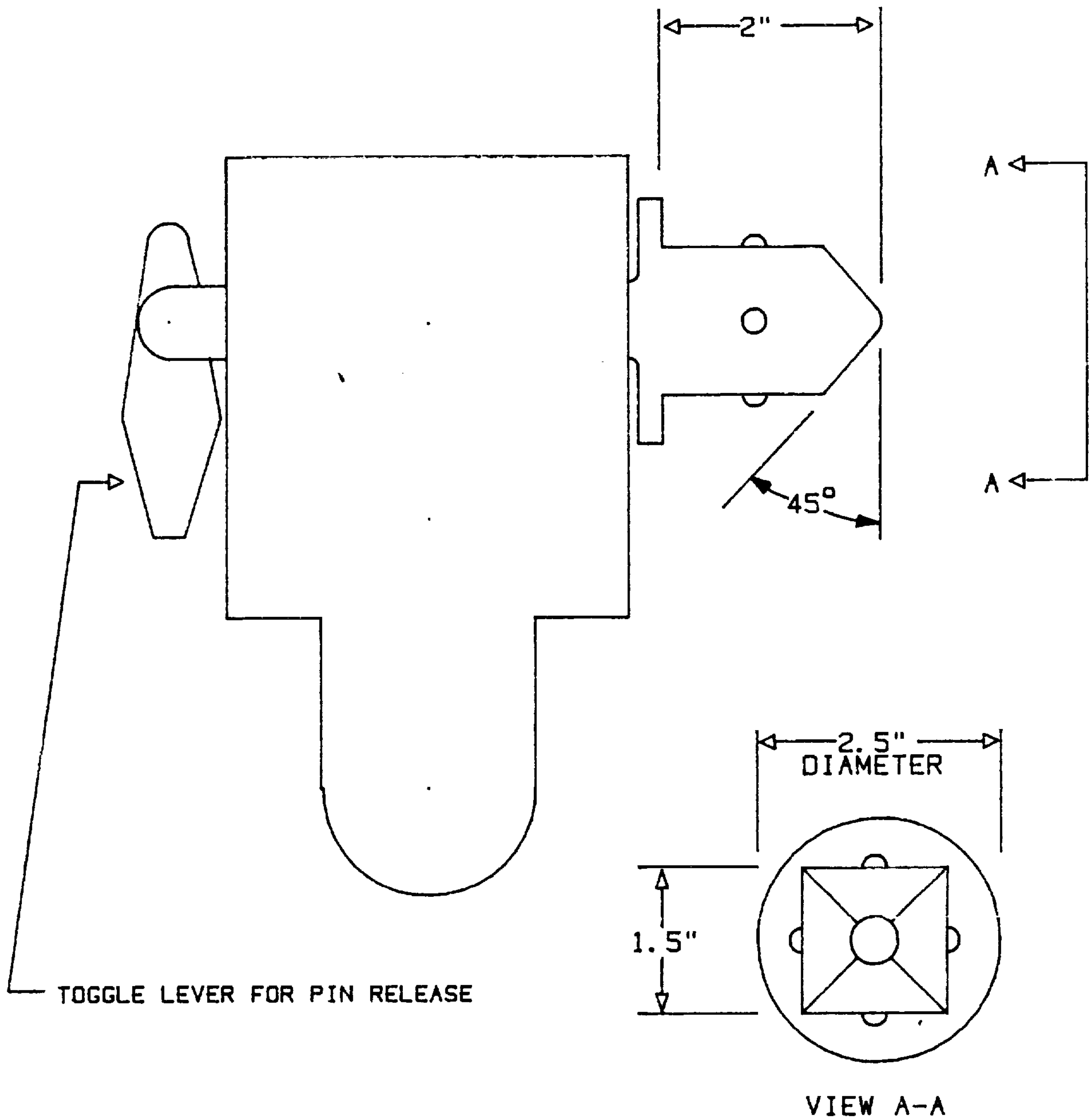

FIGURE 7-2
WRIST JOINT MODIFIED FOR SINGLE POINT ATTACHMENT

VIII. RECOMMENDATIONS FOR UPGRADING THE GWS FOR FLIGHT USE

As with most feasibility units, changes would have to be made in order to turn this design into "flight hardware".

1. Material Selection - All gears in the control box and wrist joint as well as the worm gear set in the elbow joint are standard "off-the-shelf" components. Through proper material selection, some components could become smaller and still react the anticipated loads.

2. Thermal Concerns - Time needs to be devoted to a thermal study to determine if special coatings are required to protect the hardware.

3. Tool Stowage - In the event that the waist attachment using the Mini Work Station attachment points on the HUT is retained, then the MWS will not be used. The retractable tether of the MWS would not be required since the GWS functions as a superior restraint, however, tool board mounting is still considered important. In an effort to reduce required inventories, it seems sensible to use Manipulator Foot Restraint (MFR) tool boards as interchangeable items for GWS and MFR operations. Integration of the MFR tool boards into the GWS design should be relatively easy to accomplish.

4. Hard Upper Torso (HUT) Attachment vs. Foot Restraint

   The present intent of the GWS restraint is to use either the foot restraint or the waist restraint. An adaptation to this is the combined use of the foot restraint with a "soft" attachment to the suit where loads would not be as high at the HUT as a hard connection through the MWS attachment points. The major concern with a hard waist attachment is that with a foot restraint available to push against, the EVA crewman would be able to generate forces well in excess of the limitations of the MWS attachment points on the HUT.

5. Weight Reduction

   The GWS hardware has excess material in a number of areas which was intentionally left there in order to reduce machining costs. No lightening holes were used except for the face gears in the elbow joint.

IX. SUMMARY/CONCLUSIONS

Neutral buoyancy testing indicated that the selected gear ratios are adequate for all motions and that the worm gear final drives provide positive locking of the joints. The foot restraint is a modified Shuttle foot restraint exchanging the left and right heel locks and repositioning the toe hoops to allow down-tube mounting at the center of the platform as well as to make emergency egress faster.

Waist attachment is presently hard mount at the Mini Work Station attachment points on the HUT. This is intended for use without the foot restraint to prevent overloading the HUT. Should the foot restraint be used, mounting at the waist should be "soft" such as a fabric strap.

The Generic Work Station/Restraint System meets all of its design requirements and, with minor modifications, can be configured for flight use.